N92-10881

METEORITE SPECTROSCOPY AND CHARACTERIZATION OF ASTEROID SURFACE MATERIALS

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The asteroids and comets are the surviving primordial remnants of the early solar system. Because of their small size, they have limited potential for internally driven thermal evolution. Thus, these minor bodies are composed either of primitive materials that are essentially unaltered samples accreted from the solar nebula, or of such materials that were altered by transient heat sources during the very earliest epoch of solar system history, a period dominated by processes quite different than those seen in the present solar system.

The asteroids and meteorites provide our only direct record of the conditions and of the processes in the inner regions of the solar system during the formation epoch and during the initial period of solar system evolution. The asteroids provide significant constraints on conditions and processes as a function of heliocentric distance. The meteorites provide detailed constraints on the timing and sequence of conditions and processes in the solar nebula and early solar system. Asteroidal studies utilize the chronologies and models from the meteoritical investigations. Meteorite studies draw upon the observed distribution of materials within the asteroid belt to constrain the models of their origin and of nebular temperature and compositional gradients.

The mineralogical characterization of an asteroid's surface assemblage can provide significant insight into the history of that body. Such an assemblage is the product of the initial composition (chemistry, oxidation state, volatile inventory, etc.) and the conditions (temperature, pressure, gravitational field strength) under which the system was altered. Asteroids with mineral assemblages similar to specific meteorite types can reasonably be inferred to have undergone geochemical processes similar to those which produced the meteoritic assemblage.

In the present research program, the analysis of visible and near-infrared reflectance spectra is the primary means used to determine surface mineralogy and petrology of individual asteroids. These individual studies provide the data to investigate the broader relationships between the asteroids and meteorites (to establish a spatial context for the more detailed meteorite data) and between asteroids at different heliocentric distances (to establish the nature of nebular compositional gradients and the distribution of post-accretionary thermal events). It seems unlikely that any significant portion of the diverse asteroidal population will be visited by spacecraft within the professional lifetimes of most current investigators. Therefore, asteroid mineral characterizations from earth-based telescopic studies will remain our primary means of investigating the nature and history of most of these minor planets for the near future.

The purpose of this research program is to improve our understanding of the origin, evolution, and inter-relationships of the asteroids; of their relationships to the meteorites; and of the processes active and the conditions present in the early inner solar system. Empirical information from the study of asteroids and the meteorites is essential to the adequate development and testing of the theoretical models for the accretion of the terrestrial planets, and for their early post-accretionary evolution.

The recent results of two aspects of this research program are outlined in the following sections.

Asteroid Igneous Processes: Several asteroid classes (types M,A,E,V,R,S) appear to be composed primarily or exclusively of igneous assemblages formed by the melting and density-controlled separation of the metal and the various silicate phases[1,2]. The observed mineral assemblages indicate that different bodies within this population experienced a wide range histories[3]. Recent efforts have focused on the nature and selectivity of the asteroidal heating mechanisms and the igneous processes within the parent bodies of the present asteroids and meteorites[4]. The large variation within the diverse S-class has been investigated using available asteroid survey spectra. Figure 1 shows the distribution of two spectral parameters for igneous asteroids which were observed as a part of the 52-color asteroid survey[5]. The wide range in mafic mineral assemblages indicates a wide range in peak temperatures (from about 1000C to >1600C)[3,4].

The mineralogic variations seen among the igneous asteroids obviously represent a range of depths within their parent planetesimals (e.g. 16 Psyche [NiFe metal] from the core of its parent body, 4 Vesta [basaltic] from the crust, 446 Aeternitas [pure olivine] from the residual or cumulate mantle). An important additional source of the mineralogic variety among the igneous asteroids is the efficiency of phase segregation within the parent bodies. The large scale separation of solid and liquid phases within a parent body is a function of the density contrast between phases, the local gravitational force (body size and depth) and the degree of melting (peak temperature).

Rotational spectral variations are used to constrain the compositional gradients within individual asteroids to assess the efficiency of melt segregation which in turn constrains body size and peak temperature. Efficient melt segregation requires either a large body (a relatively strong gravitational field) or high temperatures (to produce large degrees of melt fraction and hence to lower the resistance to phase migration). For example, the silicate portion of the S-asteroid 113 Amalthea is composed of nearly pure olivine with only a minor (8 ± 2 wgt %) calcic pyroxene and shows no significant variation in lithology with rotation[4]. Unless it is a fragment of a parent planetesimal much larger than most S-asteroids, the efficient segregation of such a homogeneous assemblage either as a cumulate or residuum requires complete melting or a very high degree of partial melting. Either option places the peak temperature within its parent body near or above the olivine solidus at about 1600C.

If the original assemblages in the parent planetesimals were chondritic, then relative displacement from the chondritic (OC) field (outlined on Figure 1) is a first-order measure of the degree of igneous differentiation. Relative distance from the OC-field is also a function of the efficiency of phase segregation and hence of body size (gravitational field) and peak temperature (melting fraction).

Spinel-Bearing Asteroids and the Nebular Compositional Gradient: Most cosmochemical models assume that nebular solids exhibited a significant compositional gradient as a function of heliocentric distance. Independent data on the original nebular material at various heliocentric distances

would provide important constraints on the temperature and pressure profiles in the solar nebula.

During the analysis of data from the 52-color asteroid survey, several anomalous spectra were identified[6]. The ECAS and 52-color data for S-type asteroids 387 Aquitania and 980 Anacostia both exhibit a broad spinel feature extending longwards from about 1.3-1.6um[7]. These features were initially identified as the second pyroxene band centered near 2um. However, these spectra do not show the expected 1um feature which should be at least as strong as the 2um feature in a pyroxene-dominated assemblage. Moreover the similar orbital elements of Aquitania and Anacostia suggest that they are fragments of a single parent body.

Spinel, a magnesium-aluminum oxide mineral, is a major constituent of the calcium-aluminum inclusions (CAI's) which are characteristic of CV meteorites such as Allende. These CAI's represent a suite of high temperature condensates and/or refractory residues formed by intense heating in some portions of the solar nebula. The presence of spinel features in an asteroidal spectrum provides a very strong indication of assemblages analogous to the CV3 and CO3 meteorites. Since this assemblage must be nearly unaltered nebular material, it's presence requires that at this particular heliocentric distance when the parent planetesimal of these two asteroids accreted, the nebula contained a relatively high proportion of CAI-type grains mixed with a C3-type mineral assemblage.

ACKNOWLEDGMENT: This research was supported in whole or in part by NASA Grant NAGW-642.

REFERENCES: [1]Bell et al. (1989) in Asteroids II, U. Arizona Press, Tucson, pp. 921-945. [2]Gaffey et al. (1989) ibid, pp. 98-127. [3]Gaffey et al. (1990) LPSC XXI, 399-400. [4]Gaffey (1991) LPSC XXII, 423-424. [5]Bell et al. (1988) LPSC XIX, 57-58. [6]Burbine et al. (1991) Meteoritics, submitted. [7]Rajan and Gaffey (1984) LPSC XV, 284-285.

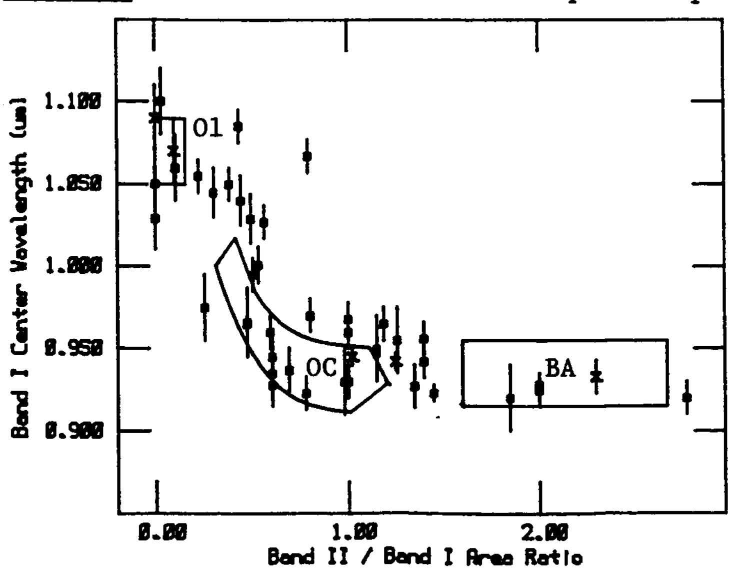

Figure 1: The distribution of two spectral parameters related to silicate mineral composition and abundance for asteroids observed in the 52-color asteroid survey. The three outlined regions include silicate assemblages composed of pure olivine, those similar to ordinary chondrite silicates, and those of basaltic composition. The mineralogy of the silicate fraction of S-asteroids range from essentially pure olivine to basaltic. Displacement from the OC-zone is a indication of increased igneous differentiation.